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ICEBREAKING WITH AIR CUSHION TECHNOLOGY

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Introduction:

Traditionally, ships engaged in icebreaking duties have slowly evolved through improvements in hull form and propulsion to large deep-draught ships of high displacement and very high installed power. Their hull forms are specialized, and they are specially strengthened to combat the high loads associated with ramming ice at speed and with ice impacts. Speed of advance through thick ice is slow, and is only achieved at the expense of high power usage, involving the consumption of large quantities of fuel. With the present concern over conservation of non-renewable fuels, improvements in icebreaking efficiency must be sought, particularly since new sources of fuel lie in the Arctic Ocean.

An icebreaker needs not only to break the ice, but also to leave a cleared track astern in order to allow passage of more conventional vessels; the clearance achieved is generally not very great. In addition to assisting navigation, icebreaking operations are also required for flood control and assisting waterside facilities in maintaining ice-free water.

Despite the long evolution and concentrated efforts, and the increasing need to improve icebreaking, there have been few break-throughs to revolutionize the process. However, experiments in Canada over the past four years with air cushion technology indicate that its use may have considerable potential in reducing energy required, operating in areas of water too shallow for icebreakers, and in providing substantially greater clearance of ice astern. It is the purpose of this note to review the experiences to date, and discuss the methods by which ice is broken with air cushion technology.

Historical Review:

For clarity in the text, relevant details of the vehicles and trials mentioned are tabulated in Tables 1 and 2. (Page 8).

The first significant demonstration was at Yellowknife in the winter of 1971-72, when ACT-100 (Fig. 1) continuously broke 27 ins. (68.6 cm) of freshwater ice at speeds of up to 4 mph (6.4 km/hr). The track was not significantly cleared of ice, and was slightly wider than the vehicle's beam. Further tests of ACT-100's icebreaking performance were made at Tuktoyaktuk during simulated ferry trials in the winter of 1972-73; in which the available 22 ins. (56 cm) of ice was broken, and successive passes resulted in breaking the ice flows up considerably. These trials were the first in which the Canadian Government was directly involved, and included measurements of the ice characteristics; the results are reported in Refs. 1 and 2, and the trials are illustrated in Figs. 2 and 3.

In order to determine whether size was a significant parameter, further tests using the smaller Terracross H-119 air cushion trailer were made at Montreal in the spring of 1973. While these tests were abbreviated, the available 9 ins. (23 cms) of ice were easily broken (Fig. 4).

Up to this time, the Air Cushion Vehicle Division of the Ministry of Transport's Marine Administration had been the prime motivating force, with valuable assistance from the Department of the Environment. However, with an apparent potential of significance, it was considered that this phenomenon required further and more detailed study, and an Interdepartmental ACV Icebreaking Working Group was therefore formed. This Group included representatives from the NRC Ship and Marine Dynamics Laboratory and Building Research, D.O.I.T.C., Dept. of the Environment, Canadian Coast Guard, Transportation Development Agency with the ACV Division providing the Chairman and Secretary. Experiments up to this time had used vehicles which had no self-propulsion capability, and one of the first priorities was seen to be to attempt some trials which would not rely on winch and cable propulsion. Studies showed that to give the towed trailers self-propulsion for navigation in ice was not practical, and therefore it was decided to use a conventional tug to push an air cushion trailer placed across its bow. It was also decided to carry out trials using the self-propelled Voyageur operated by the Canadian Coast Guard.

Both of these experiments took place in the winter of 1973-74. The Hover-JaK HJ-15 and Terracross H-119 trailers were tested in Toronto Harbour being pushed by a harbour tug, under TDA sponsorship, while the Voyageur conducted trials at Parry Sound. The Toronto trials were beset by unseasonably warm weather, and equipment operating problems, but again the ability of the air cushion to break ice was established. In Parry Sound, the Voyageur enjoyed much better conditions, and it was

clearly demonstrated that ice could be broken up to a thickness just less than the cushion pressure head, at speeds up to about 7 mph (11.2 km/hr). However, it was also discovered that a very much more powerful method of icebreaking existed, whereby much thicker ice could be broken at about twice the speed. Since this had been totally unexpected, formal experiments were abbreviated, but it was established that up to 20 ins. (51 cm) of ice could be broken continuously at speeds of 12-15 mph (12-24 km/hr). The Parry Sound trials are reported in Refs. 3 and 4 and illustrated in Figs. 5, 6 and 7.

It appeared that the two distinct methods of operation should be examined more closely, and from discussion it was considered that the slow-speed method might have application in assisting ships to navigate through ice, if it were associated with a ship. The ACV Division and the Canadian Coast Guard therefore contracted for model tests to be carried out, using a CCG icebreaker, the Norman McLeod Rogers, with the ACT-100 fitted across and around the bow. These tests took place in the Arctec Incorporated model basin at Savage, Md. in July, 1974, and are fully reported in Ref. 6. Briefly, these tests indicated that the ship's resistance could be reduced by up to about 30% by use of the "ACV bow", and that there was a marked reduction in ice coverage in the track astern. Some aspects of these tests are illustrated in Figs. 8, 9 and 10. As a direct result of these trials, a design study for an ACV icebreaking platform to be fitted to the CCG Icebreaker "Montcalm" was commissioned in early 1975; Bell Aerospace Canada won the study contract, and completed the study in April, 1975. An artist's impression of the platform is shown in Fig. 11.

Meanwhile, in the winter of 1974-75, the CCG Voyageur was operated on icebreaking duties based at Montreal; a considerable amount of successful icebreaking was accomplished, and it was mainly due to this success a minimum of quantitative data was gathered. Two significant operations demonstrated on ACV's capability to break ice in shallow water; both the Chateauguay River and Rivière des Prairies were cleared to relieve the danger of flooding; in the latter case, an agglomerate of ice up to 16 ft. (5 m) thick over a distance of some three miles (4.8 km) was cleared.

These trials and operations have clearly established that air cushion technology has a large role to play in icebreaking; so far, all experience has been over first year fresh water ice, and it has yet to be seen how far this can be extended to heavier, multi-year and rough ice.

Further trials will be conducted in the winter of 1975-76, details of which are being worked out.

Applications:

The experiences at Montreal show that there is a clear advantage in using air cushion technology for flood control in areas too congested or too shallow for conventional icebreakers. The rate of icebreaking is rapid; in some operations, Voyageur was breaking a track up to 60 feet (18 m) wide at speeds up to 25 mph (40 km/hr). Normally, flood control in such areas is accomplished by small, shallow draft tugs of limited capability, or by blasting which has attendant dangers.

It was also shown that large areas of lake ice could be rapidly broken up and dispersed, provided that there is a current to carry the broken ice away. Without a current or pressure of flood water, there is very little clearance or dispersion of ice. Even without the clearance, however, breaking up an intact ice sheet is frequently required in harbours to allow local movement of shipping, and the use of an ACV, with high deployment speed and maneuverability has considerable advantages over a conventional icebreaker. The Coast Guard SRN-5 at Vancouver broke ice in the Fraser River in early 1975, allowing fishing vessels to leave port. Such local clearance and breaking of ice could effectively extend navigation seasons in areas where local ice problems occur. The high deployment speed of self-propelled ACVs also allows rapid response to icebreaking requirements in remote areas; for example, a Voyageur could travel 200 miles over ice in about five hours to an operational area, while an icebreaker might take 30 hours to cover the same distance.

By attaching a high-pressure air cushion platform to the bow of a ship, navigation through ice beyond the capability of the ship to break should be possible. In ice which is within the ship's capability, the power required to proceed at a given speed is significantly reduced, effectively giving the ship a reserve of power to increase speed or to increase the thickness of ice which may be negotiated. Of at least equal significance, this application leaves a substantially clear track astern which would allow easy navigation for a following ship. Such a bow could be fitted to an icebreaker to improve its icebreaking performance, or to a conventional ship to provide an ice navigation capability.

While considerably more work requires to be done, there appears to be no scale effect on the ability of an ACV to fail an ice sheet, other than there is almost certainly a relationship between size and weight of the ACV and the thickness which may be broken. Therefore, any requirement to break lake or river ice can be met by using an ACV. Logging booms could be moved for longer periods probably by using a relatively small ACV to break the ice, and a similar sized vehicle could probably keep ice-free water available around installations such as hydro dams and plants with high consumption of water.

Technical discussion - slow speed method:

Failure of an ice sheet by an ACV moving at slow speed (less than 6-7 mph, 9.6-11.2 km/hr) appears to depend entirely upon the cushion pressure head being greater than the ice thickness. This has been demonstrated by ACT-100 at Tuktoyaktuk and Yellowknife, and by Voyageur at Parry Sound. In the latter case, direct observation and movie film confirm this.

With the ACV approaching the edge of an ice sheet, or operating over a hole in an ice sheet, the water level beneath the vehicle is depressed, relative to the surrounding surface, by the air cushion pressure head. As the vehicle moves on to the ice sheet, the dispersed water level allows an air cavity to form between the ice and water, which extends forwards with the advancing vehicle. The ice sheet, with the buoyant force of water removed, is now in cantilever, and fails under its own weight when the stress in the ice at the forward end of the cavity, due to that weight, exceeds the failure stress of the ice. This depends upon the thickness and nature of the ice; typically, the flexural strength of first year lake or river ice is 90 p.s.i. (6.33 kg/cm^2), with a modulus of elasticity of 600,000 p.s.i. (42,200 kg/cm^2). Analyses to determine the lengths of cantilever before failure have been made, and are reported in Refs. 3 and 6; due to the many theories which may be employed, results predicted by different methods may vary considerably.

Significant thicknesses of ice can only be broken by this method if the cushion pressure is relatively high; this implies considerable drag at high speed, and it is not practical to make these vehicles self-propelled for high speed.

This method of icebreaking is therefore most suitable for use in conjunction with a ship for propulsion. It is in this context that the model trials conducted at Savage were initiated. The reduction in resistance noted in these trials has yet to be formally described, but it is apparently due to the fact that the ship no longer has to break, submerge or turn the ice; these functions are performed by the air cushion. With the ice already in motion before the ship's bow encounters it, the ship's bow wave continues to turn the submerged ice outward, displacing it beneath the ice sheet either side and resulting in a clear track astern. The reduction in resistance is discussed further in Reference 5.

Technical Discussion - high speed method:

This method, while having been demonstrated as very much more powerful in terms of ice thickness and speed, is very much less clearly defined as to its limits. This is partly due to the lack of quantitative experimental data, and partly due to the difficulty of applying any established theory. Considerable reference has been made by researchers, exemplified by Ref. 7, to work carried out by Nevel (Ref. 8). However, Nevel provides a solution which gives a symmetrical pattern of deflections in the ice sheet surrounding a moving load, which clearly cannot exist in practice. Possibly a major difference between Nevel's theory and the practical situation is that the ice sheet fails beneath the load in the case of a moving ACV, and therefore the all-important boundary condition of an intact ice sheet, on which the theory depends, is no longer present.

Failure of the ice sheet in this method occurs involuntarily when the Voyageur ACV operates within the speed range 12.5-25 mph (20-40 km/hr). This statement is specific since it relates to the only observed and documented icebreaking by this method to date. Within this speed range, a large wave builds up in the ice sheet astern of the vehicle with a large amplitude, and a wavelength of approximately one craft-length. The ice sheet certainly cracks, if not fails, beneath the craft and thus weakened, it fails completely on the wave crest. Ice failed by this method has been observed to be up to 20 ins. (50.8 cm) thick, and the limiting thickness has not been established.

Clearly, this is a very powerful method of icebreaking for which a theory has yet to be established in order that a general appreciation of vehicle capabilities may be understood. From the experiences of Voyageur, it would appear that the action is initiated by operating at a speed which equates to the overwater hump speed. However, Nevel's theory previously referenced indicates that the ice deflection reaches a maximum at a "critical speed" which also equates to the overwater hump speed for the shallow water over which Voyageur has primarily operated. While it has already been pointed out that Nevel's theory may not be valid, this aspect is a coincidence which must be examined in determining the appropriate theory.

A suggested approach is to examine the possibility that a hump wave is formed in the water beneath the ice, in response to the moving depression in the ice caused by the vehicle, and equate the energy in that wave to that required to fail the ice sheet. Since the failure appears to be progressive along the wave length, this may be an extremely complex analysis; it may, however, explain why the wave has been observed at speeds rather higher than can be explained by either hump wave theory or by floating ice theories.

Concluding remarks:

It is apparent that air cushion technology has a considerable role to play in assisting icebreaking operations and navigation through ice-infested waters. At this time, the knowledge is restricted to relatively smooth first year fresh water ice, but there appears to be no technical reason why experience should not be extended to include first year sea-ice and ultimately to lightly rafted and ridged ice. The shallow-water, high speed and maneuverability of air cushion vehicles, coupled with their relatively low crew requirements and power make them specially suitable for specific operations in difficult situations.

TABLE 1

Parameters of Air Cushion Vehicles used in Icebreaking Tests

Name	Overall Length (ft)	Overall Breadth (ft)	Cushion Depth (ft)	All-up Weight (lbs)	Maximum Lift Power (shp)	Cushion Pressure at AUW (in.H_2o)
ACT-100	75	57	4.0	580,000	1470	27.7
VOYAGEUR	65	34	4.0	90,000	1200	10.5
H-119	44	19.7	2.4	53,400	196	19.5
HJ-15	40	18	2.4	43,000	356	15

TABLE 2

Full Scale Parameters for ACV Icebreaker Trials

Vehicle	Date	Location	Ice Thickness Broken (in)	Cushion Pressure (in.H_2o)	Approximate Vehicle Weight (lbs)
ACT-100	1971-72	Great Slave Lake	27	27.7	580,000
			20*	20	424,000
ACT-100	1972-73	Tuktoyuktuk	20^-	25	524,000
TERRACROSS H-119	1973	Montreal	9**	16.3	38,100
VOYAGEUR	1974	Parry Sound	9.13	10	90,000
TERRACROSS H-119	1974	Toronto Harbour	9	10.6	30,000
HJ-15	1974	Toronto Harbour	9-10	11.7	36,400

* Ice did not fail - ** Maximum available

References:

1. Report on ACV ferry trials phase 1 - unpublished MOT report.
2. Problems posed by all weather highway river crossings - a proposed solution - R.G. Wade, CASI Journal September, 1973.
3. Icebreaking trials, Voyageur ACV, February 1974, D. Dickens.
4. Icebreaking trials with the Bell Aerospace Voyageur ACV - Dickens and Dutfield - CASI Journal December, 1974.
5. Improvements in icebreaking using air cushion technology - Wade, Edwards & Kim - SNAME, April 1975.
6. Mathematical Model of icebreaking with an ACV - Lecourt & Kim Arctec Tech Note 39-2.
7. Model Tests of an Arctic SEV over model ice - Lecourt, Kotras and Kordenbrock, SNAME, April 1975.
8. Moving loads on a floating ice sheet - D.E. Nevell, CRREL, 1968.

Figures:

FIG. 1 - ACT-100 at Yellowknife, 1972

FIG. 2 - ACT-100 at Tuktoyaktuk, 1972.
Ice thickness 22" (56cm)

FIG 3 - ACT-100 at a weight of 250 tons, breaking 22 inches of ice during MOT winching trials at Tuktoyaktuk, November, 1972.

FIG. 4 - Terracross H-119 at Montreal, 1973. Ice thickness 9" (23cm)

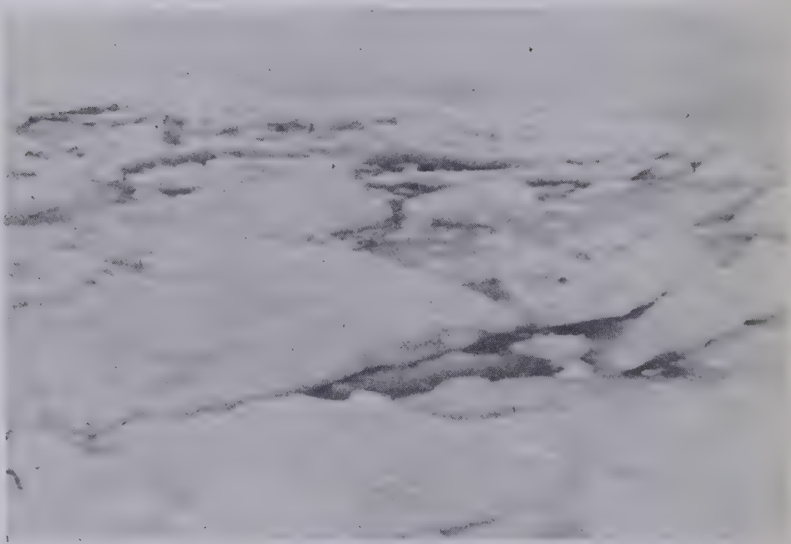

FIG. 5 - 12" (30.5cm) ice After 1 pass at 12mph (19km/hr)

FIG. 6 - 12" (30.5cm) ice After 5 passes at 12mph (19km/hr)

FIG. 7 - 7.5" (19cm) ice
After 1 pass at 4mph (6.5km/hr)

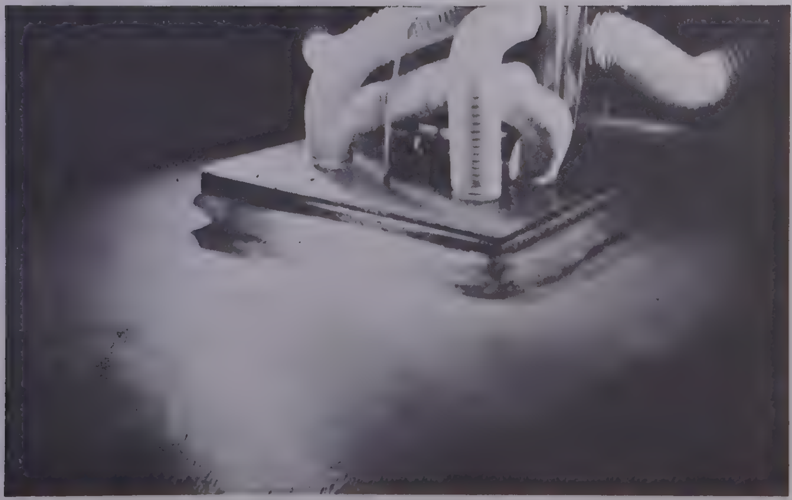

FIG 8 - Model ACV bow mounted
on icebreaker for tank tests, Savage, Md., 1974

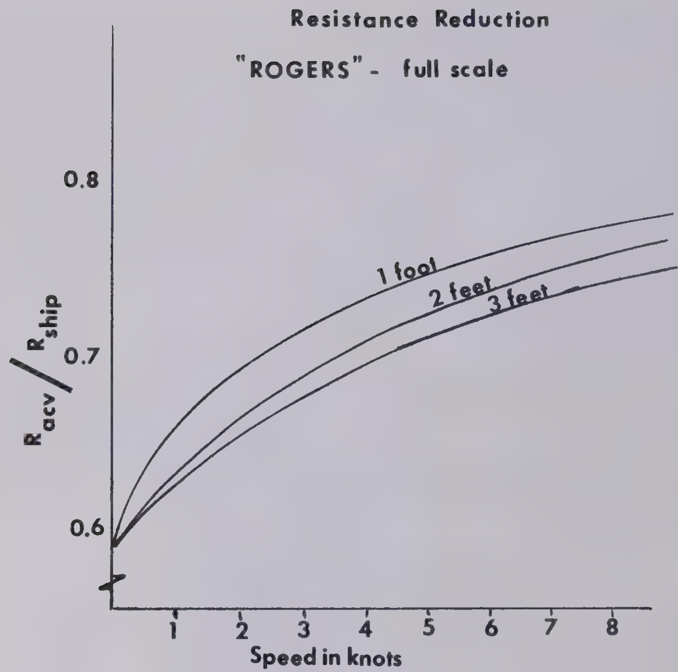

FIG. 9 - Model trials - clearance of track

In the foreground, the track is that left by the icebreaker with the ACV bow attached. Near the top of the picture, the track is that left when the ACV bow was removed.

FIG. 10 - Effect of ACV bow on resistance of ship in intact ice.

FIG. 11 - Bell Aerospace artist's impression of ACV bow fitted to icebreaker "Montcalm"